Probe Study Examples of Technology Development Plans

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Probe Study Technology Notes

- What was needed in the plan
  - Current state of all new technologies in the concept design
  - Concept required state of all new technologies in the concept design
  - Plan to get from current to the needed states
    - Technology development steps for each technology
    - Rough technology development schedule that aligned with mission start
    - Rough technology development cost estimate
    - Recognized what work was done, what work was funded but still in progress, and what work was needed and not funded.
      - The schedule for funded work in progress should mesh with the study's technology plan
- TRL
    - For each technology decide what determines TRL 5 and TRL 6
      - We used our own judgement based on NASA TRL guidelines
      - Explain the rationale in the Technology section
    - We also gave our assessment of the current TRL

The Exo-S Gaps: Where We Are/Where We Need To Be

ID	Title	Description	Current	Required
S-1	Control edge-scattered sunlight	Limit edge-scattered sunlight with optical edges that also handle stowed bending strain	Graphite edges meet all specs. except sharpness, with edge radius ≥ 10 µm	Edge radius ≤ 1 µm, Reflectivity $\leq 12\%$, Stowed radius ≥ 1.5 m
S-2	Demonstrate contrast and suppression performance and validate optical models	Demonstrate flight contrast and suppression, and validate starshade diffraction model in testbed that scales to flight design	Achieved contrast of 3×10^{-10}, except near petal edges, and suppression OF ~1e-6, in testbed at Fresnel # $\approx$ 500, at 632 nm wavelength	Contrast $\leq 1\times10^{-10}$, over all space from IWA to OWA, suppression < 10^{-9} in testbed at Fresnel # ≤ 25, over 250 nm bandpass in visible/NIR.
S-3	Demonstrate lateral formation-sensing accuracy	Demonstrate lateral formation-sensing accuracy consistent with keeping telescope in dark shadow created by starshade	Centroid accuracy $\geq 1\%$ of a pixel is common, benefit from long integration times	Lateral sensing error ≤ 20 cm, estimate centroid positions to $\leq 0.3\%$ of optical resolution
S-4	Demonstrate flight-like petal fabrication and deployment	Establish petal at TRL 5	Demonstrated manufacturing tolerances with early prototype, including: flat optical edges, no blankets, no interface to launch restraint, and deployment control system	Demonstrate manufacturing tolerances with flight-like petal, including: sharp optical edges, optical shield, interfaces to launch restraint and deployment control system
S-5	Demonstrate inner disk deployment with optical shield	Establish perimeter truss at TRL 5	Demonstrated deployment tolerance with 12-m Astromesh antenna, no blankets, no outrigger struts, no launch restraint	Demonstrate deployment tolerances with 20-m perimeter truss, optical shield, outrigger struts, launch restraint

Exo-S Gap S-5: Progress to Date in Tech Development

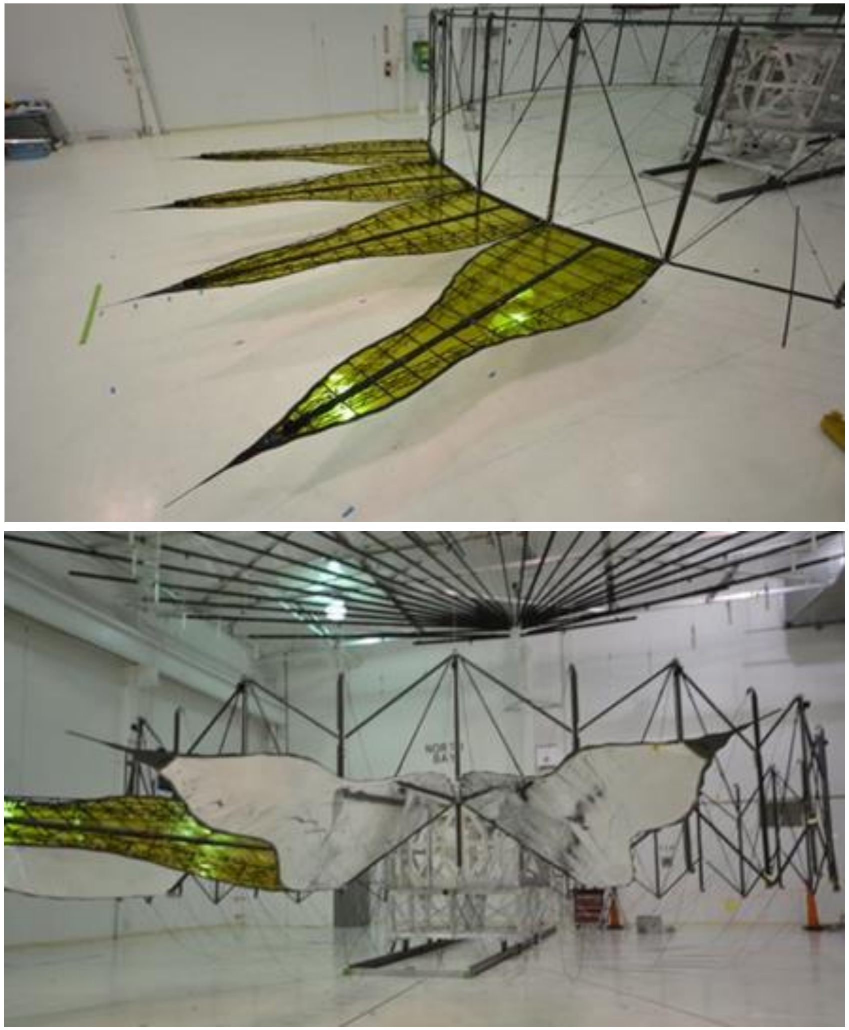

Figure 9.5-1. Deployed position tolerance demonstration. Petal root positions are measured after each of 20 deployments.

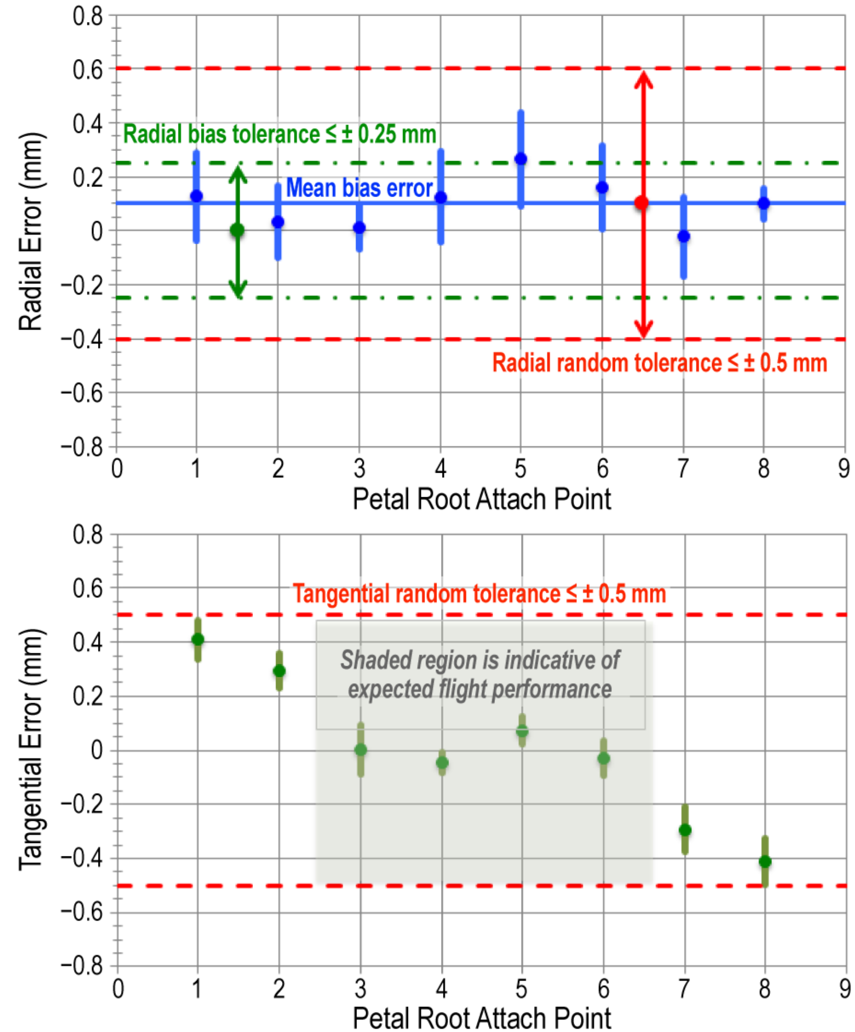

Figure 9.5-2. Measured deployment errors (3 σ with 90% confidence) are all within tolerance allocations.

Exo-S Gap S-5: The Plan to TRL 5 with Rough Timeline

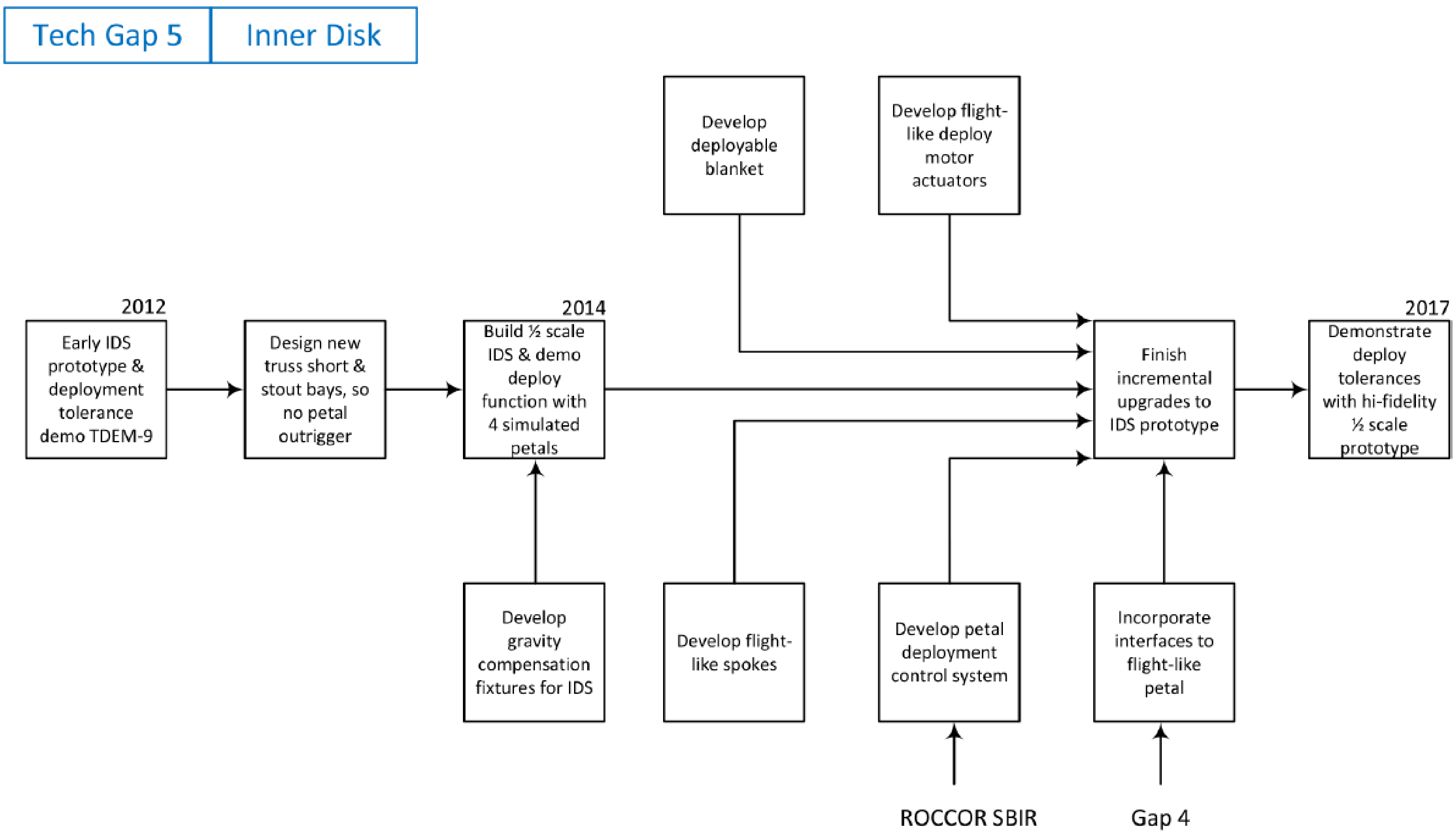

Figure C-4. Starshade inner disk structure development technology gap retirement flow plan.

The Funding/Investment Situation

Table C-1. Starshade technology development task cost estimates.

ID #	Title	Tasks to Resolve	Cost Estimate
S-1	Control edge-scattered sunlight	a) Upgrade testbed and operate b) Verify specification and develop design solution b') Modeling support to NGAS c) Develop & test edge prototype + tip section d) Develop & operated edge segment testbed: strain test, radius profile, in-plane profile	[redacted]
S-2	Demonstrate contrast and suppression performance and validate optical models	a) Provide test article with sharp edges b) Develop lab testbed b') Model edge phenomenon c) Characterize sensitivities in field c') Modeling support to NGAS	[redacted]
S-3	Demonstrate lateral formation-sensing accuracy	a) Develop image processing and control system algorithms, develop FGS breadboard, demo perf. in Princeton optical testbed	[redacted]
S-4	Demonstration of flight-like petal fabrication and deployment	a) Develop petal blanket testbed & POC blanket a') Develop prototype petal blanket b) Petal and system designs d) Procure petal level metrology system & operate e) Produce full-set of optical edges and tip section f) Procure petal materials/parts (long-lead composites) g) Assemble petal, integrate blanket/edges/tip, deploy test & demo manufacturing tolerance	[redacted]
S-5	Demonstration of inner disk deployment with optical shield	a) Develop POC truss at 1/2 scale (no blanket) and demo functionality b) Develop gravity compensation fixture in bldg 299 c) Design blanket and produce bench size mockup d) Produce prototype blanket, integrate w/ POC truss, demo deploy tolerances e) Produce full set of simulated petals f) Petal unfurl control system g) Integrate unfurl control system & simulated petals and demo contiguous unfurl/deploy*	[redacted]
			Total: [redacted]

Exo-C Progress to Date Examples

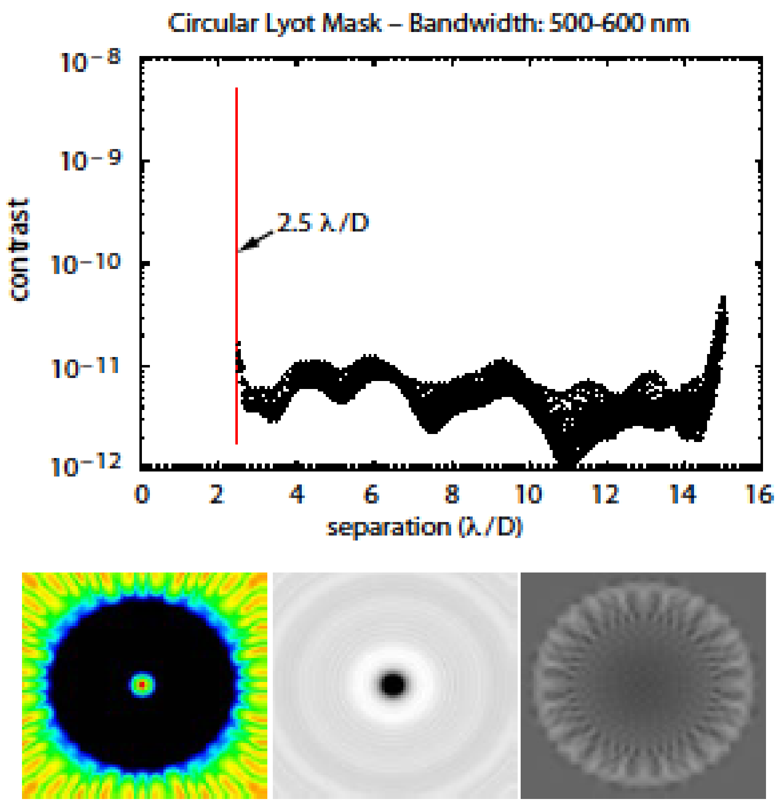

Figure 8-4. Ideal performance of circular HLC mask with raw contrast of 5.3e−12 from 2.5 to 15 λ/D and 48×48 actuator DM. Simulations are still being refined that show predicted performance with jitter at ~5e−10 (Trauger 2012).

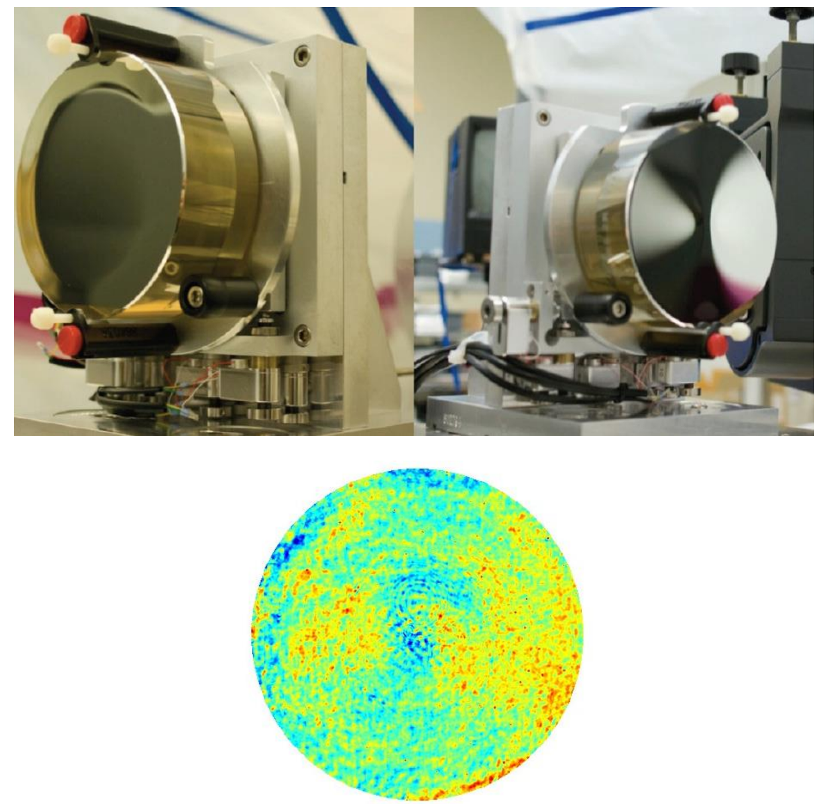

Figure 8-5. PIAA mirrors manufactured by Tinsley (top) and a surface error map of the second mirror (bottom) showing a surface error of 3.8 nm rms (Image source: http://exep.jpl.nasa.gov/files/exep/10_Belikov_2013_ExoPAG_v3.pdf).

Exo-C Gap List plus Rough Estimates of Schedule and Cost

Category	Item(s)	Required (2017)/ Desired (2020)	Current Capability	AFTA Plan? (Poberezhskiy JPL Document)	ROM Time/Cost
Coronagraph	HLC static	Required: 10^{-9} raw contrast at an angular separation of 2 λ/D (0.16″ at 550 nm) and 20% band in presence of jitter (2017) Desired: contrast: 5×10^{-10} contrast, same IWA, 20% band with jitter (2020)	2×10^{-9} contrast at IWA of 3 λ/D, 20% bandwidth, in static system with linear mask.	10^{-8} raw contrast at 550 nm narrowband	2 years [redacted]
Coronagraph	PIAA static	Required: 10^{-9} raw contrast at IWA 2 λ/D, bandwidth 20%, in a dynamic system (2017) Desired: raw contrast: 5×10^{-10} at IWA 2.0 λ/D, 20% bandwidth, in presence of jitter (2020)	1e^{-8} at of 2 λ/D and 550 nm with 10% bandwidth in static system	10^{-8} raw contrast at 550 nm, 10% band (with PIAACMC, a variant of PIAA)	2 years, [redacted] Include hardware development, new mirrors (5 nm rms), apodizer (D/1000 shape)
Coronagraph	VVC static	Required: 10^{-9} raw contrast at an angular separation of 2 λ/D, (20% bandwidth, in presence of jitter (2017) Desired: contrast 10^{-9} IWA 1.7 λ/D, bandwidth 20% (2020)	1e^{-8} at of 2 λ/D and 550 nm with 10% bandwidth in static system	10^{-8} raw contrast at 550 nm narrowband	2 years, [redacted] Include central defect, broadband mask
Coronagraph	All dynamic	Repeat all static tests with Exo-C worst case dynamic condition, requirement 0.8 RMS mas/axis	Not yet demonstrated, CBE 0.28 mas RMS/axis post FSM correction	Dynamic testing included, but performance range not specified (Poberezhskiy JPL Document).	2 year [redacted]
Algorithm Development	ADI, CDI	Required: factor of 10 improvement in contrast Desired: factor of 30	Factor of ~30, but under idealized conditions	TBD, but most likely factor of 10	1 year [redacted]
Binary Star	Demo	Required: Spillover light contrast 3×10^{-8} at 8λ equivalent separation. (2017). Desired: 3e10^{-9} achieved by mirror polishing or wavefront control	10^{-7} at 8" by HST	None	1 year [redacted] for WFC